PREDICTION OF PERCENT BODY FAT FOR U.S. NAVY WOMEN FROM BODY CIRCUMFERENCES AND HEIGHT

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SUMMARY

- OPNAVINST 6110.1B established percent body fat (%BF) as the basis for weight control decisions, replacing height/weight tables. Tables based upon the work of Wright, Dotson, and Davis allowing prediction of %BF from biceps, forearm, neck, abdominal and thigh circumferences were accepted for use on an interim basis. These tables were developed using U.S. Marine Corps personnel and had validities of $r=0.73$ (se = 4.11 % BF units). This report covers cross-validation of the equation of Wright, et al. on a sample of U.S. Navy personnel and development and cross-validation of a new equation which offers improved prediction of %BF for U.S. Navy female personnel.
- An anthropometric assessment consisting of 8 skinfold thicknesses and 11 body circumference measures, as well as height and body weight, was made of 214 female naval personnel. Body density was determined by underwater weighing and used to calculate %BF.
- The validity of the Wright equation was assessed by correlation of %BF predicted by the equation and %BF determined from underwater weighing. The correlation coefficient was found to be 0.80 and the standard error of measurement on the prediction was 4.19 %BF units. The equation was found to overpredict lean personnel (%BF < 15), and underpredict personnel whose %BF was above 22, including those having body fat above the 30% Navy body fat standard. It was decided to develop an alternative equation.
- Factor analysis of the anthropometric variables indicated that a suitable equation might be developed which relied only upon body circumference measures and height. A predictive equation was developed from a forward, stepwise multiple regression utilizing logarithmic transformations of circumferences, and height measures as predictors of body density from underwater weighing. The final equation has a multiple correlation coefficient of 0.85 and a standard error of estimate of 0.00796 g/cc (equivalent to 3.72 %BF units).
- This final equation was cross-validated on two samples of female military personnel: a sample of 66 Canadian Forces women whose data was obtained from another laboratory; and a sample of 80 U.S. Navy women participating in another study in our laboratory. The correlation between %BF determined from our predictive equation and %BF based upon underwater weighing was 0.80 with a standard error of measurement equal to 4.36 %BF units for the Canadian Forces sample, and 0.87 with a standard error of 4.04 %BF units for the U.S. Navy sample.
- It is recommended that this new equation be adopted for the determination of %BF for female Navy personnel.

PREDICTION OF PERCENT BODY FAT FOR U.S. NAVY WOMEN

FROM BODY CIRCUMFERENCES AND HEIGHT

1. INTRODUCTION

In October of 1981 the Navy promulgated Chief of Naval Operations Instruction 6110.1B entitled "Health and Physical Readiness." One of the policy changes enacted by this instruction was a change from height/weight standards to a percent body fat standard (%BF) as the basis for weight control decisions. In the instruction %BF is assessed by measurement of biceps, forearm, neck, abdominal, and thigh circumferences using tables which were constructed based upon an equation developed by Wright, Dotson, and Davis (1980) for use with U.S. Marine Corps personnel. The equation (with all measurements in cm) is as follows:

$$\begin{aligned}\%\ \text{BODY FAT} = {} & (1.051 \times \text{BICEPS CIRCUMFERENCE}) \\ & -(1.522 \times \text{FOREARM CIRCUMFERENCE}) \\ & -(0.879 \times \text{NECK CIRCUMFERENCE}) \\ & +(0.326 \times \text{ABDOMEN II CIRCUMFERENCE}) \\ & +(0.597 \times \text{THIGH CIRCUMFERENCE}) \\ & +0.707\end{aligned}$$

In their original sample, %BF estimated using the equation of Wright and his co-workers correlated reasonably well ($R=0.73$, $se=4.11$) with body fat determined from underwater weighing. For this reason and because of the relative ease with which circumference measurements are made, the Navy adopted this equation for use in its instruction on an interim basis. However, this equation was developed on Marine Corps personnel, and inasmuch as anthropometric predictive equations such as this one tend to be population specific, it is necessary to cross-validate the results of Wright, et al. on a sample of Navy women.

This report presents the results of cross-validation of the Wright equation on a sample of Navy women. In addition, we present a new equation with improved prediction of %BF for female Navy personnel, as well as a cross-validation of this new equation on an independent sample of female military personnel.

2. METHODS

2.1 Subjects

The subjects in this study were 214 female naval personnel, aged 18 to 44 years (mean = 26.5). These participants were drawn from both land and shore based commands. Each participant was briefed upon the nature of the study, attendant risks and benefits, and gave voluntary consent prior to testing. Characteristics of the study participants are given below in Table 1.

Table 1

PARTICIPANT CHARACTERISTICS[a]

Age (yrs)	26.5 (±5.18)
Height (cm)	164.5 (±6.58)
Weight (kg)	61.68 (±9.30)
Residual Lung Volume (l)	1.083 (±0.330)
Body Density (g/ml)	1.03787 (±0.01489)
% Body Fat[b]	27.04 (±6.85)

[a]Values represent mean (± standard deviation)

[b]% Fat from Siri, 1961: %BF = 100[(4.95/Body Density)-4.50]

2.2 Anthropometric Assessment

During anthropometric assessment, subjects were clad in a two-piece swimming suit or shorts and top. Standing height was measured to the nearest 0.25 inch and body weight recorded to the nearest 0.25 lb. Skinfold and circumference measurements were obtained by one of two trained investigators. A series of 8 skinfold and 11 circumference measurements were made twice in sequence. If the difference between two skinfold measurements exceeded 5% at a given site or the difference between two circumferences exceeded 1 cm at a given site, a third measurement was taken at that site. The mean of all measurements taken at a site was used for analysis.

2.2.1 Skinfold Measurement

During skinfold assessment, the subject was standing relaxed. Measurements were taken on the right side of the body with a Harpenden skinfold caliper (British Indicators Ltd., St. Albans, Kerts, UK) and recorded to the nearest 0.1 mm.

Skinfold thicknesses were measured at the following sites:

Biceps: Midway between the acromion and olecranon processes on the anterior aspect of the arm, with the fold running parallel to the long axis of the arm (Behnke and Wilmore, 1974).

Triceps: Midway between the acromion and olecranon processes on the posterior aspect of the arm, with the fold running parallel to the long axis of the arm (Behnke and Wilmore, 1974).

Subscapular: Just beneath the inferior angle of the scapula with the fold sloping downward laterally at 45 degrees (Carter, 1982).

Chest: Just medial to the anterior axillary border with the fold running on a line between the axilla and opposite hip (Behnke and Wilmore, 1974).

Midaxillary: On the midaxillary line at the level of the xyphoid, with the fold running along the line of the rib (Yuhasz, 1974).

Anterior suprailiac: Five to 7 cm above the anterior superior iliac spine on a line to the anterior axiliary border, with fold sloping downward, medially at 45 degrees (Carter, 1982).

Abdominal: Vertical fold 3 to 5 cm to the right of the umbilicus (modified from Carter, 1982).

Front thigh: On the anterior aspect of the thigh midway between the trochanterian and the proximal border of the patella, with the fold running parallel to the long axis of the thigh. The leg was relaxed and slightly bent (Carter, 1982).

2.2.2 Circumference Measurement

All circumference measurements (except arm extended) were made with the subject standing relaxed. All measurements (except neck circumference) were made in the plane orthogonal to the long axis of the body segment being measured. Measurements were made with a calibrated, fiberglas reinforced measuring tape (Scoville-Dritz). The tape was applied so that it conformed to but did not depress the skin surface. Measurements were recorded to the nearest 1.0 mm. Chest and abdominal circumferences were measured at the end of a normal expiration. All limb circumferences were measured on the right side of the body.

Circumferences were assessed at the following sites:

Neck: Just inferior to the larynx with tape sloping slightly downward to the front (Behnke and Wilmore, 1974).

Shoulders: At the level of the second costo-sternal articulation (Behnke and Wilmore, 1974).

Chest I: Just inferior to the axilla.

Abdomen I: At the level of minimal abdominal width, approximately midway between the xyphoid and the umbilicus (Behnke and Wilmore, 1974).

Abdomen II: At the level of the umbilicus (Behnke and Wilmore, 1974).

Thigh: Just inferior to the gluteal fold (Behnke and Wilmore, 1974).

Calf: Maximal girth of the calf (Behnke and Wilmore, 1974).

Arm extended: Maximal girth of the mid-upper arm (over the biceps) with the arm abducted to 90 degrees, hand supinated, and elbow locked in maximal extension (Behnke and Wilmore, 1974).

Arm relaxed: Midway between the acromion and the olecranon processes with the arm hanging relaxed at the side (Carter, 1982).

Forearm: Maximal girth of the forearm with the arm hanging relaxed at the side.

Wrist: Minimal girth just distal to the styloid processes of the radius and ulna (Behnke and Wilmore, 1974).

2.3 Residual Lung Volume Determination

Residual lung volume (RV) was measured by closed-circuit helium dilution (Ruppel, 1975, pp 6-8) using a modular lung analyzer (model 3002, Warren E. Collins, Inc., Braintree, MA). Residual lung volume was assessed prior to underwater weighing with the subject in a position similar to that assumed during the underwater weighing: seated and bent forward at the waist.

2.4 Underwater Weighing

Underwater weight was assessed in a 4 x 8 x 7 ft. glass-fronted, rectangular tank in which a chair constructed of 3/4 in. polyvinyl chloride pipe was suspended from a load cell (model 81C, Revere Corp. of America, Wallingford, CT). Signals from the load cell were amplified (model 7P122, Grass Instrument Co., Quincy, MA) and the amplified signals digitized (model 47310A, Hewlett-Packard, Fort Collins, CO) and fed into a programmable desk-top calculator (model 9825T, Hewlett-Packard, Fort Collins, CO). In-house software designed for this application, processed the load cell values, determined stable weight values which occurred during a single weighing, and printed them out for inspection.

Underwater weighing was performed according to the method of Goldman and Buskirk (1961), with the two following modifications: 1) RV was determined outside the weighing tank prior to immersion; and 2) All subjects completed at least six underwater weighings. In cases where a plateau of two or more similar, heavy readings had not been reached by the sixth trial, weighing was continued until this plateau was reached. Final underwater weight was computed as an average of the two heaviest readings. Body density (BD) was calculated using the formula of Buskirk (1961) and converted to %BF using the formula of Siri (1961).

2.5 Statistical Analysis Procedures

Statistical analyses were performed using the Statistical Package for the Social Sciences (Nie, et al., 1975). The purpose of the analyses was twofold.

Firstly, the validity of regression equations developed by Wright and his co-workers (1980) was investigated. Cross-validation was assessed by calculation of the correlation coefficient and the standard error of measurement between values of %BF determined from underwater weighing and %BF values predicted from the equation of Wright, et al.

Secondly, factor analysis and multiple regression techniques were employed in order to develop generalized regression equations, based on a Navy sample, for predicting BD (which can be used to calculate %BF) from anthropometry. The factor analysis was performed to determine the pattern of clustering of the anthropometric variables and thereby aid in the selection of variables to be used in later regression analysis.

Factors were extracted by the method of principal components. The minimum eigenvalue for extraction was set equal to 1.0. It was anticipated there would be significant correlations between the extracted factors, since such factors might well represent subelements of some larger concept, for example, body size. The factors were, therefore, subjected to oblique rotation (delta = 0) which does not force the rotated factors to be uncorrelated. Factor scores were calculated for the rotated factors, and correlations between these scores and BD, body volume, lean body mass, and fat body mass derived from underwater weighing were calculated in order to aid in identification of the nature of the factors.

Following the factor analysis, a series of multiple regression analyses were performed. Body density was utilized as the dependent variable. In each analysis, anthropometric variables entered the equation in a forward, stepwise fashion. Variables were added to the equation until the resultant change in the square of the correlation coefficient was less than 0.01 (1% of the accounted-for variance).

The analysis proceeded in three steps. First, the analysis was run using a set of anthropometric variables whose selection was guided by the results of the factor analysis. Second, the analysis was run again utilizing logarithmic transformations of the anthropometric variables which were selected in the first regression analysis. This second analysis was performed to attempt to minimize the alinearity of the relationship between anthropometric variables and BD (Durnin and Womersley, 1974; Jackson, 1978). Finally, the regression was run a third time using logarithmic transformations of linear combinations of selected anthropometric variables. The signs of these combinations were determined from the first multiple regression. The purpose of this third analysis was to determine whether or not the variables could be combined in such a fashion to allow construction of a two-way table for use in the field for %BF prediction. The selected final equation was then cross-validated on measures from two different samples: 1) an independent sample of 66 women serving in the Canadian Forces (Mr. C. Allen, DCIEM, unpublished data); and 2) a second sample of 80 Navy women studied in this laboratory as part of another study.

3. RESULTS AND DISCUSSION

3.1 Cross-validation of Wright Equation

Figure 1 is a scattergram showing the comparison of %BF predicted using the Wright equation with %BF calculated from BD. The line of identity is indicated on the figure. The correlation between %BF predicted from the Wright equation and that from BD in this sample was 0.80 (std. err. meas. = 4.19 %BF units). Figure 1 indicates a certain nonlinearity in the relationship between predicted and calculated %BF. Additionally, %BF appears to be overestimated for hydrostatically-determined body fat percentages less than 18. Above 22%, the Wright equation appears to underestimate %BF.

Curvilinearity of the relationship between calculated %BF and anthropometric variables has been previously shown by Durnin and Womersley (1974) and by Jackson (1978). This curvilinearity can be minimized by modelling the relationship as logarithmic functions of anthropometric variables.

In general, the equation of Wright and his co-workers predicts %BF as well as most general equations relying on circumference measures (Jackson and Pollock, 1977 and see Table 6). However, because of the general underprediction of body fat for values near the body fat standard of 30% fat (values which have importance for administrative decisions), it was deemed worthwhile to attempt to develop other better-fitting equations.

3.2 Development of a Navy-specific Equation

The factor analysis of the anthropometric measures was performed in part to determine whether or not it was necessary to include skinfold thickness measures in our equation. Initial attempts to perform the factor analysis failed due to the high colinearity among variables. To avoid this problem, highly correlated variables were combined prior to factor analysis. Midaxillary, subscapular, and anterior suprailiac were added to create a composite "trunk skinfold"; extended-arm and relaxed-arm biceps circumferences were added to create an

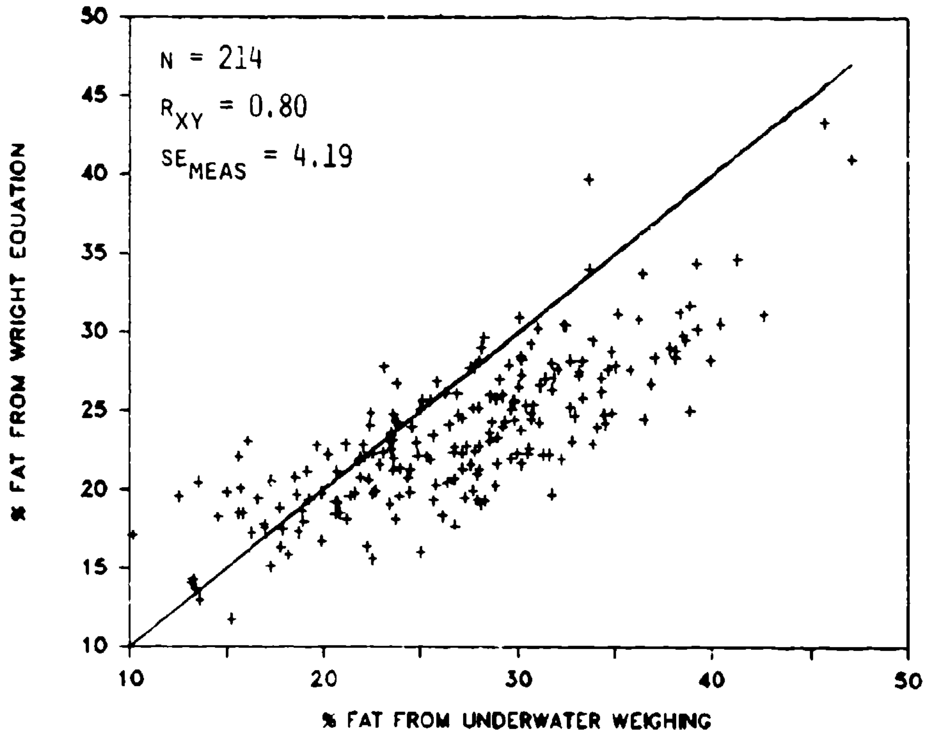

FIGURE 1: Scattergram showing relationship between percent body fat predicted from the equation of Wright, et al. and that determined from underwater weighing.

"arm circumference"; abdomen I and abdomen II circumferences were added to create an "abdominal circumference"; and thigh and chest I circumferences were deleted from this analysis because of their high correlations with hip and shoulder circumferences respectively.

Two factors were identified with eigenvalues of 1.0 or greater. The factor pattern coefficients of these variables for the two factors are shown in Table 2. The clusters of variables obtained when variables were grouped by factor pattern coefficients are shown in Table 3. As can be seen, all the skinfolds and abdominal circumferences show "salient" loadings (factor pattern coefficient $\geq$ 0.3; Gorsuch, 1974, pp 184-185) on factor 1. Most of the circumferences load saliently on factor 1 and factor 2. Height and wrist circumference load saliently only on factor 2.

Table 2

FACTOR PATTERN COEFFICIENTS OF ANTHROPOMETRIC VARIABLES

	Factor 1.	Factor 2.
Biceps skinfold	.920	-.060
Chest skinfold	.903	-.163
Trunk skinfold	.891	.035
Triceps skinfold	.864	-.050
Abdominal skinfold	.844	-.027
Thigh skinfold	.817	-.134
Abdominal circumference	.712	.324
Arm circumference	.704	.363
Hip circumference	.614	.466
Calf circumference	.543	.432
Height	-.292	.821
Wrist circumference	.250	.721
Shoulder circumference	.447	.650
Neck circumference	.474	.563

Table 3

SALIENT LOADING PATTERNS AMONG ANTHROPOMETRIC VARIABLES*

Factor 1.	Factor 1. & 2.	Factor 2.
Biceps skinfold	Abdominal circumference	Height
Chest skinfold	Arm circumference	Wrist circumference
Trunk skinfold	Hip circumference	
Triceps skinfold	Calf circumference	
Abdominal skinfold	Shoulder circumference	
Thigh skinfold	Neck circumference	

* A variable loading was considered salient if its factor weight equaled or exceeded 0.3 (Gorsuch, 1974, pp 184-185).

In order to help assign meaning to these factors, correlations were computed between factor scores for each participant and her BD, body volume, fat body mass, and lean body mass values. These correlations are presented in Table 4.

Table 4

FACTOR SCORE CORRELATIONS

	Factor 1.	Factor 2.
Body density	-0.782	-0.008*
Body volume	0.573	0.532
Lean mass	0.017*	0.777
Fat mass	0.750	0.243

* Not significant ($p > 0.05$)

Based upon this sample, it appears there are two general factors, one representing the amount of fat tissue, and the other representing the amount of lean tissue. These correlational results are similar to those reported previously from this laboratory for male U.S. Navy personnel (Hodgdon and Beckett, 1984).

As can be seen in Table 2, all of the skinfold thicknesses have salient weightings on only the fat mass factor (factor 1). Height and wrist circumference load only on the lean mass factor (factor 2). The remaining circumference measures show salient weightings on both factors. Factor structures and loading patterns similar to those presented in Tables 2 and 3 have been reported by Jackson and Pollock (1976). These factor patterns are also similar to those reported previously by this laboratory for anthropometric measures obtained for male Navy personnel (Hodgdon and Beckett, 1984). The major difference between the pattern of loadings presented here for women and those reported previously for men is in the pattern presented for women there is no circumference which has a salient weighting only on the fat mass factor. Among the data for males, abdomen II circumference loaded only on the fat mass factor.

Despite the lack of a circumference loading saliently only on factor 1, it was decided to use only the circumferences, height, body weight, and age as variables in the regression to predict BD. Our rationale was these are the measures most reliably made in the field by personnel with minimal training.

The best model determined from multiple regression involving body circumferences and height measured in cm is:

$$\begin{aligned}\text{BODY DENSITY} = & -[.35004 \times \text{LOG}_{10}(\text{ABDOMEN I} + \text{HIP} - \text{NECK})] \\ & +[.22100 \times \text{LOG}_{10}(\text{HEIGHT})] \\ & +1.29579\end{aligned}$$

The final selected set of variables contains one circumference (abdomen I) which weighs highly on the fat mass factor, two circumferences with moderate loadings on each factor (hip and neck circumferences), and height which is saliently weighted only on the lean mass factor. Body weight and age were included in the variable list for the model but did not enter. The multiple correlation coefficient between BD predicted from this equation and from BD based upon underwater weighing was 0.85. The standard error of measurement was 0.00796 g/cc, equivalent to a standard error of 3.72 %BF units.

The equation shown above (henceforth referred to as the NHRC equation) utilizes a logarithmic transformation of a linear composite of abdomen I, hip, and neck circumferences. The multiple regression coefficient and standard error of the estimate did not differ between this equation and one formed from the linear combination of the log transforms of the individual circumferences. The circumferences were combined prior to logarithmic transformation in our final equation because this technique made it easier to construct two-way tables for the prediction of body fat using this equation.

Figure 2 is a scattergram showing the relationship between %BF predicted from the NHRC equation and that determined from underwater weighing. As is apparent, there is less curvature in the relationship between the two measurements than was the case for prediction using the equation of Wright and his co-workers (see Figure 1).

A table for use in the field listing %BF (calculated from BD using the equation of Siri, 1961) as a function of the sum of abdomen I and hip circumference minus neck circumference measurements and height (all measurements in inches) is provided as Appendix A to this report.

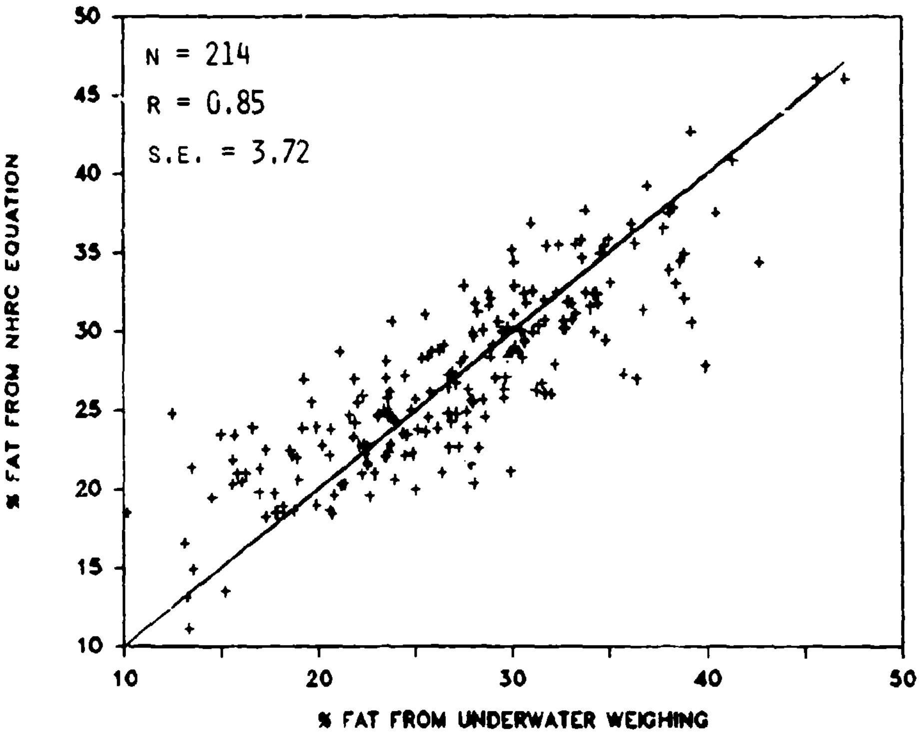

FIGURE 2: Scattergram showing relationship between percent body fat predicted from the NHRC equation and that determined from underwater weighing.

3.3 Cross-validation of the Navy-specific Equation

The NHRC equation was cross-validated using two different samples of data on military women. One data sample consisted of %BF and anthropometric measures made on 66 women serving in the Canadian Forces (Mr. C. Allen, DCIEM, unpublished results). The other data sample consisted of %BF and anthropometric data collected in this laboratory on 80 female U.S. Navy personnel participating in another study. Sample descriptions and cross-validation results are provided in Table 5.

Table 5

CROSS-VALIDATION RESULTS

	Canadian Forces Sample	U.S. Navy Sample
Sample size	66	80
Mean age	32.7	25.9
Mean height (cm)	163.2	164.4
Mean weight (kg)	64.0	63.0
Mean %BF from underwater weight[a]	29.20	26.55
Mean %BF predicted from NHRC equation[a]	27.94[b]	26.31
Correlation coeff.	0.80	0.87
Std. err. of meas.	4.36	4.04

[a]% Fat from Siri, 1961: $\%BF = 100[(4.95/\text{Body Density})-4.50]$

[b]Differs significantly ($p<0.05$) from %BF by underwater weighing

The results presented in Table 5 indicate the NHRC equation cross-validated rather well using the two samples from military populations. As might be expected given the population specificity found with such equations, the correlation between measured and predicted %BF was higher for the U.S. Navy cross-validation sample than it was for the Canadian Forces sample. However, this difference was not significant ($p>0.05$; Diem, 1962, p 62 & 31). Correlation for the Navy cross-validation sample was greater, but not significantly different from the multiple correlation found with the equation development sample.

3.4 Comparisons with other Equations

The scientific literature is of course replete with equations which can be used to predict BD or %BF from anthropometric variables. For a subset of those equations, cases in which our measures could be used in the equations, we cross-validated existing equations on our data set. The cross-correlations between %BF or BD predicted by the referenced equations and %BF or BD determined from underwater weight are provided in Table 6.

Table 6

CROSS-CORRELATIONS USING OTHER EQUATIONS

Reference[1]	Criterion Variable[2]	Predictor Variables[3]	r	Mean Diff.[4]	Std. Err. of Meas.[5]
(1)[a]	BD	S	0.81	-1.61*	4.13
(2)[a]	BD	S,A	0.78	-0.52	4.38
(3)	%BF	C	0.80	3.41*	4.19
(4), #1	BD	S	0.75	2.76*	4.89
(4), #2	BD	C	0.81	-0.70*	4.12
(4), #3	BD	S,C	0.81	1.48*	4.21
(5)	%BF	C,H	0.76	-3.57*	4.56

[1] (1) Durnin & Womersley (1974); (2) Berres, et al. (1980); (3) Wright, et al. (1980); (4) Katch & McArdle (1973); (5) Brennen (1974).

[2] BD= Body Density; %BF=Percent Body Fat

[3] S=Skinfolds; C=Circumferences; A=Age; H=Height; W=Weight

[4] Expressed as %BF, Difference = measured %BF - predicted %BF

[5] Expressed as %BF

[a] Skinfold sites differ slightly from those described here

* Differences significant ($p<0.05$)

As can be seen, correlations between predicted and calculated BD (or %BF) using the referenced equations are lower than the correlation of 0.85 seen in this sample with our equation. For three of the seven equations listed, the correlation coefficients differ significantly from 0.85. The methods for suprailiac and subscapular skinfold measurement differ slightly for the equations in references (1) and (2) in Table 6. These differences in technique should not markedly affect the correlation coefficients, although they would be expected to affect the mean difference and standard error of measurement given in the table. The equation contained in reference (1) is currently being used by the U.S. Army as the basis for %BF assessment and was included in the table for that reason.

The NHRC equation does not rely on skinfold thickness measurement and is thus easier for minimally trained personnel to use. The factor analysis results suggested that prediction of %BF in female Navy personnel might be improved by the addition of skinfold thickness measures. However, for those equations listed in Table 6 the inclusion of such measures does not appear to affect the magnitude of the correlation between predicted and measured BD.

4. CONCLUSIONS AND RECOMMENDATIONS

The equation developed on our sample of 214 U.S. Navy female personnel for the prediction of %BF appears to represent a meaningful improvement over the equation currently utilized as the basis for the tables in OPNAVINST 6110.1B. Compared to the currently used equation, utilization of the NHRC equation requires fewer circumferences (three vs. five) to be measured, and the addition of one "non-girth" measurement, height. It is still based on measures taken easily and reliably in the field. It was developed on a sample of the population upon whom it is meant to be used. The selection of an appropriate sample appears to have led to better prediction of %BF than was achieved with the equation of Wright and his co-workers which was developed on Marine Corps personnel. Based on these findings, we would recommend a change from the current assessment of %BF in female U.S. Navy personnel using the Wright equation to an assessment based upon the equation presented here.

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6. APPENDIX A

TABLES FOR THE PREDICTION OF % BODY FAT

PERCENT FAT ESTIMATION FOR FEMALES

Height (inches)

Circumference Value *	58.0	58.5	59.0	59.5	60.0	60.5	61.0	61.5	62.0	62.5
34.5:	1	0	-	-	-	-	-	-	-	-
35.0:	2	1	1	1	0	-	-	-	-	-
35.5:	3	2	2	2	1	1	0	0	-	-
36.0:	4	3	3	3	2	2	1	1	1	0
36.5:	5	4	4	4	3	3	2	2	2	1
37.0:	6	5	5	4	4	4	3	3	3	2
37.5:	7	6	6	5	5	5	4	4	4	3
38.0:	7	7	7	6	6	6	5	5	5	4
38.5:	8	8	8	7	7	7	6	6	5	5
39.0:	9	9	9	8	8	7	7	7	6	6
39.5:	10	10	9	9	9	8	8	8	7	7
40.0:	11	11	10	10	10	9	9	8	8	8
40.5:	12	12	11	11	10	10	10	9	9	9
41.0:	13	12	12	12	11	11	11	10	10	10
41.5:	14	13	13	13	12	12	11	11	11	10
42.0:	14	14	14	13	13	13	12	12	12	11
42.5:	15	15	15	14	14	13	13	13	12	12
43.0:	16	16	15	15	15	14	14	14	13	13
43.5:	17	17	16	16	15	15	15	14	14	14
44.0:	18	17	17	17	16	16	16	15	15	14
44.5:	19	18	18	17	17	17	16	16	16	15
45.0:	19	19	19	18	18	17	17	17	16	16
45.5:	20	20	19	19	19	18	18	18	17	17
46.0:	21	20	20	20	19	19	19	18	18	18
46.5:	22	21	21	20	20	20	19	19	19	18
47.0:	22	22	22	21	21	20	20	20	19	19
47.5:	23	23	22	22	22	21	21	21	20	20
48.0:	24	23	23	23	22	22	22	21	21	21
48.5:	25	24	24	23	23	23	22	22	22	21
49.0:	25	25	25	24	24	23	23	23	22	22
49.5:	26	26	25	25	24	24	24	23	23	23
50.0:	27	26	26	26	25	25	24	24	24	23
50.5:	27	27	27	26	26	26	25	25	24	24
51.0:	28	28	27	27	27	26	26	25	25	25
51.5:	29	28	28	28	27	27	27	26	26	25
52.0:	29	29	29	28	28	28	27	27	27	26
52.5:	30	30	29	29	29	28	28	28	27	27
53.0:	31	30	30	30	29	29	29	28	28	27
53.5:	31	31	31	30	30	30	29	29	28	28
54.0:	32	32	31	31	31	30	30	30	29	29
54.5:	33	32	32	32	31	31	31	30	30	29
55.0:	33	33	33	32	32	32	31	31	30	30
55.5:	34	34	33	33	33	32	32	31	31	31
56.0:	35	34	34	33	33	33	32	32	32	31
56.5:	35	35	34	34	34	33	33	33	32	32
57.0:	36	35	35	35	34	34	34	33	33	33
57.5:	36	36	36	35	35	35	34	34	34	33
58.0:	37	37	36	36	36	35	35	35	34	34
58.5:	38	37	37	37	36	36	35	35	35	34

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Circumference Value *	Height (inches) 58.0	58.5	59.0	59.5	60.0	60.5	61.0	61.5	62.0	62.5
59.0:	38	38	38	37	37	36	36	36	35	35
59.5:	39	38	38	38	37	37	37	36	36	36
60.0:	39	39	39	38	38	38	37	37	37	36
60.5:	40	40	39	39	39	38	38	37	37	37
61.0:	41	40	40	39	39	39	38	38	38	37
61.5:	41	41	40	40	40	39	39	39	38	38
62.0:	42	41	41	41	40	40	40	39	39	38
62.5:	42	42	42	41	41	40	40	40	39	39
63.0:	43	42	42	42	41	41	41	40	40	40
63.5:	43	43	43	42	42	42	41	41	40	40
64.0:	44	44	43	43	42	42	42	41	41	41
64.5:	45	44	44	43	43	43	42	42	42	41
65.0:	-	45	44	44	44	43	43	42	42	42
65.5:	-	-	45	44	44	44	43	43	43	42
66.0:	-	-	-	-	45	44	44	44	43	43
66.5:	-	-	-	-	-	45	44	44	44	43
67.0:	-	-	-	-	-	-	45	45	44	44
67.5:	-	-	-	-	-	-	-	-	45	44
68.0:	-	-	-	-	-	-	-	-	-	45
68.5:	-	-	-	-	-	-	-	-	-	-
69.0:	-	-	-	-	-	-	-	-	-	-
69.5:	-	-	-	-	-	-	-	-	-	-
70.0:	-	-	-	-	-	-	-	-	-	-
70.5:	-	-	-	-	-	-	-	-	-	-
71.0:	-	-	-	-	-	-	-	-	-	-
71.5:	-	-	-	-	-	-	-	-	-	-
72.0:	-	-	-	-	-	-	-	-	-	-
72.5:	-	-	-	-	-	-	-	-	-	-
73.0:	-	-	-	-	-	-	-	-	-	-
73.5:	-	-	-	-	-	-	-	-	-	-
74.0:	-	-	-	-	-	-	-	-	-	-
74.5:	-	-	-	-	-	-	-	-	-	-
75.0:	-	-	-	-	-	-	-	-	-	-
75.5:	-	-	-	-	-	-	-	-	-	-

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Circumference Value *	Height (inches)									
	63.0	63.5	64.0	64.5	65.0	65.5	66.0	66.5	67.0	67.5
34.5:	-	-	-	-	-	-	-	-	-	-
35.0:	-	-	-	-	-	-	-	-	-	-
35.5:	-	-	-	-	-	-	-	-	-	-
36.0:	0	-	-	-	-	-	-	-	-	-
36.5:	1	1	0	-	-	-	-	-	-	-
37.0:	2	2	1	1	1	0	-	-	-	-
37.5:	3	3	2	2	2	1	1	1	0	-
38.0:	4	3	3	3	2	2	2	1	1	1
38.5:	5	4	4	4	3	3	3	2	2	2
39.0:	6	5	5	5	4	4	4	3	3	3
39.5:	7	6	6	6	5	5	5	4	4	4
40.0:	7	7	7	6	6	6	5	5	5	4
40.5:	8	8	8	7	7	7	6	6	6	5
41.0:	9	9	8	8	8	7	7	7	6	6
41.5:	10	10	9	9	9	8	8	8	7	7
42.0:	11	10	10	10	9	9	9	8	8	8
42.5:	12	11	11	11	10	10	10	9	9	9
43.0:	12	12	12	11	11	11	10	10	10	9
43.5:	13	13	13	12	12	12	11	11	11	10
44.0:	14	14	13	13	13	12	12	12	11	11
44.5:	15	15	14	14	14	13	13	13	12	12
45.0:	16	15	15	15	14	14	14	13	13	13
45.5:	16	16	16	15	15	15	14	14	14	13
46.0:	17	17	17	16	16	16	15	15	15	14
46.5:	18	18	17	17	17	16	16	16	15	15
47.0:	19	18	18	18	17	17	17	16	16	16
47.5:	19	19	19	18	18	18	17	17	17	16
48.0:	20	20	20	19	19	18	18	18	18	17
48.5:	21	21	20	20	20	19	19	19	18	18
49.0:	22	21	21	21	20	20	20	19	19	19
49.5:	22	22	22	21	21	21	20	20	20	19
50.0:	23	23	22	22	22	21	21	21	20	20
50.5:	24	23	23	23	22	22	22	21	21	21
51.0:	24	24	24	23	23	23	22	22	22	21
51.5:	25	25	24	24	24	23	23	23	22	22
52.0:	26	25	25	25	24	24	24	23	23	23
52.5:	26	26	26	25	25	25	24	24	24	23
53.0:	27	27	26	26	26	25	25	25	24	24
53.5:	28	27	27	27	26	26	26	25	25	25
54.0:	28	28	28	27	27	27	26	26	26	25
54.5:	29	29	28	28	28	27	27	27	26	26
55.0:	30	29	29	29	28	28	28	27	27	27
55.5:	30	30	30	29	29	29	28	28	28	27
56.0:	31	31	30	30	30	29	29	29	28	28
56.5:	32	31	31	31	30	30	30	29	29	29
57.0:	32	32	32	31	31	31	30	30	30	29
57.5:	33	32	32	32	31	31	31	30	30	30
58.0:	33	33	33	32	32	32	31	31	31	30
58.5:	34	34	33	33	33	32	32	32	31	31

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Circumference Value *	Height (inches) 63.0	63.5	64.0	64.5	65.0	65.5	66.0	66.5	67.0	67.5
59.0:	35	34	34	34	33	33	33	32	32	32
59.5:	35	35	35	34	34	34	33	33	33	32
60.0:	36	35	35	35	34	34	34	33	33	33
60.5:	36	36	36	35	35	35	34	34	34	33
61.0:	37	37	36	36	36	35	35	35	34	34
61.5:	38	37	37	37	36	36	36	35	35	35
62.0:	38	38	37	37	37	36	36	36	35	35
62.5:	39	38	38	38	37	37	37	36	36	36
63.0:	39	39	39	38	38	38	37	37	37	36
63.5:	40	39	39	39	38	38	38	37	37	37
64.0:	40	40	40	39	39	39	38	38	38	37
64.5:	41	41	40	40	40	39	39	39	38	38
65.0:	41	41	41	40	40	40	39	39	39	38
65.5:	42	42	41	41	41	40	40	40	39	39
66.0:	43	42	42	41	41	41	40	40	40	39
66.5:	43	43	42	42	42	41	41	41	40	40
67.0:	44	43	43	43	42	42	42	41	41	41
67.5:	44	44	43	43	43	42	42	42	41	41
68.0:	45	44	44	44	43	43	43	42	42	42
68.5:	-	45	44	44	44	43	43	43	42	42
69.0:	-	-	45	45	44	44	44	43	43	43
69.5:	-	-	-	-	45	44	44	44	43	43
70.0:	-	-	-	-	-	45	45	44	44	44
70.5:	-	-	-	-	-	-	-	45	44	44
71.0:	-	-	-	-	-	-	-	-	45	45
71.5:	-	-	-	-	-	-	-	-	-	-
72.0:	-	-	-	-	-	-	-	-	-	-
72.5:	-	-	-	-	-	-	-	-	-	-
73.0:	-	-	-	-	-	-	-	-	-	-
73.5:	-	-	-	-	-	-	-	-	-	-
74.0:	-	-	-	-	-	-	-	-	-	-
74.5:	-	-	-	-	-	-	-	-	-	-
75.0:	-	-	-	-	-	-	-	-	-	-
75.5:	-	-	-	-	-	-	-	-	-	-

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Height (inches)

Circumference Value *	68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5
34.5:	-	-	-	-	-	-	-	-	-	-
35.0:	-	-	-	-	-	-	-	-	-	-
35.5:	-	-	-	-	-	-	-	-	-	-
36.0:	-	-	-	-	-	-	-	-	-	-
36.5:	-	-	-	-	-	-	-	-	-	-
37.0:	-	-	-	-	-	-	-	-	-	-
37.5:	-	-	-	-	-	-	-	-	-	-
38.0:	0	0	-	-	-	-	-	-	-	-
38.5:	1	1	1	0	0	-	-	-	-	-
39.0:	2	2	2	1	1	1	0	0	-	-
39.5:	3	3	3	2	2	2	1	1	1	0
40.0:	4	4	3	3	3	3	2	2	2	1
40.5:	5	5	4	4	4	3	3	3	2	2
41.0:	6	5	5	5	5	4	4	4	3	3
41.5:	7	6	6	6	5	5	5	4	4	4
42.0:	8	7	7	7	6	6	6	5	5	5
42.5:	8	8	8	7	7	7	6	6	6	6
43.0:	9	9	9	8	8	8	7	7	7	6
43.5:	10	10	9	9	9	8	8	8	7	7
44.0:	11	10	10	10	9	9	9	9	8	8
44.5:	12	11	11	11	10	10	10	9	9	9
45.0:	12	12	12	11	11	11	10	10	10	10
45.5:	13	13	12	12	12	12	11	11	11	10
46.0:	14	14	13	13	13	12	12	12	11	11
46.5:	15	14	14	14	13	13	13	12	12	12
47.0:	15	15	15	14	14	14	13	13	13	13
47.5:	16	16	15	15	15	15	14	14	14	13
48.0:	17	17	16	16	16	15	15	15	14	14
48.5:	18	17	17	17	16	16	16	15	15	15
49.0:	18	18	18	17	17	17	16	16	16	15
49.5:	19	19	18	18	18	17	17	17	17	16
50.0:	20	19	19	19	18	18	18	18	17	17
50.5:	20	20	20	19	19	19	19	18	18	18
51.0:	21	21	20	20	20	20	19	19	19	18
51.5:	22	21	21	21	21	20	20	20	19	19
52.0:	22	22	22	22	21	21	21	20	20	20
52.5:	23	23	22	22	22	22	21	21	21	20
53.0:	24	23	23	23	23	22	22	22	21	21
53.5:	24	24	24	23	23	23	23	22	22	22
54.0:	25	25	24	24	24	24	23	23	23	22
54.5:	26	25	25	25	24	24	24	24	23	23
55.0:	26	26	26	25	25	25	24	24	24	24
55.5:	27	27	26	26	26	25	25	25	25	24
56.0:	28	27	27	27	26	26	26	25	25	25
56.5:	28	28	28	27	27	27	26	26	26	25
57.0:	29	29	28	28	28	27	27	27	26	26
57.5:	30	29	29	29	28	28	28	27	27	27
58.0:	30	30	29	29	29	29	28	28	28	27
58.5:	31	30	30	30	29	29	29	29	28	28

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Height (inches)

Circumference Value *	68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5
59.0:	31	31	31	30	30	30	29	29	29	28
59.5:	32	32	31	31	31	30	30	30	29	29
60.0:	32	32	32	32	31	31	31	30	30	30
60.5:	33	33	32	32	32	31	31	31	31	30
61.0:	34	33	33	33	32	32	32	31	31	31
61.5:	34	34	34	33	33	33	32	32	32	31
62.0:	35	34	34	34	34	33	33	33	32	32
62.5:	35	35	35	34	34	34	33	33	33	33
63.0:	36	36	35	35	35	34	34	34	33	33
63.5:	36	36	36	35	35	35	35	34	34	34
64.0:	37	37	36	36	36	35	35	35	35	34
64.5:	38	37	37	37	36	36	36	35	35	35
65.0:	38	38	37	37	37	37	36	36	36	35
65.5:	39	38	38	38	37	37	37	36	36	36
66.0:	39	39	39	38	38	38	37	37	37	36
66.5:	40	39	39	39	38	38	38	37	37	37
67.0:	40	40	40	39	39	39	38	38	38	37
67.5:	41	40	40	40	39	39	39	39	38	38
68.0:	41	41	41	40	40	40	39	39	39	38
68.5:	42	41	41	41	40	40	40	40	39	39
69.0:	42	42	42	41	41	41	40	40	40	39
69.5:	43	42	42	42	42	41	41	41	40	40
70.0:	43	43	43	42	42	42	41	41	41	40
70.5:	44	43	43	43	43	42	42	42	41	41
71.0:	44	44	44	43	43	43	42	42	42	41
71.5:	45	44	44	44	43	43	43	43	42	42
72.0:	-	45	45	44	44	44	43	43	43	42
72.5:	-	-	-	45	44	44	44	44	43	43
73.0:	-	-	-	-	45	45	44	44	44	43
73.5:	-	-	-	-	-	-	45	44	44	44
74.0:	-	-	-	-	-	-	-	45	45	44
74.5:	-	-	-	-	-	-	-	-	-	45
75.0:	-	-	-	-	-	-	-	-	-	-
75.5:	-	-	-	-	-	-	-	-	-	-

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Circumference Value *	Height (inches) 73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5
34.5:	-	-	-	-	-	-	-	-	-	-
35.0:	-	-	-	-	-	-	-	-	-	-
35.5:	-	-	-	-	-	-	-	-	-	-
36.0:	-	-	-		-	-	-	-	-	-
36.5:	-	-	-	-	-	-	-	-	-	-
37.0:	-	-	-	-	-	-	-	-	-	-
37.5:	-	-	-	-	-	-	-	-	-	-
38.0:	-	-	-	-	-	-	-	-	-	-
38.5:	-	-	-	-	-	-	-	-	-	-
39.0:	-	-	-	-	-	-	-	-	-	-
39.5:	0	-	-	-	-	-	-	-	-	-
40.0:	1	1	0	0	-	-	-	-	-	-
40.5:	2	2	1	1	1	0	0	-	-	-
41.0:	3	2	2	2	2	1	1	1	0	0
41.5:	4	3	3	3	2	2	2	2	1	1
42.0:	4	4	4	4	3	3	3	2	2	2
42.5:	5	5	5	4	4	4	3	3	3	3
43.0:	6	6	5	5	5	5	4	4	4	3
43.5:	7	7	6	6	6	5	5	5	5	4
44.0:	8	7	7	7	6	6	6	6	5	5
44.5:	8	8	8	8	7	7	7	6	6	6
45.0:	9	9	9	8	8	8	7	7	7	7
45.5:	10	10	9	9	9	9	8	8	8	7
46.0:	11	10	10	10	10	9	9	9	8	8
46.5:	12	11	11	11	10	10	10	9	9	9
47.0:	12	12	12	11	11	11	11	10	10	10
47.5:	13	13	12	12	12	12	11	11	11	10
48.0:	14	13	13	13	13	12	12	12	11	11
48.5:	14	14	14	14	13	13	13	12	12	12
49.0:	15	15	15	14	14	14	13	13	13	13
49.5:	16	16	15	15	15	14	14	14	14	13
50.0:	17	16	16	16	15	15	15	15	14	14
50.5:	17	17	17	16	16	16	16	15	15	15
51.0:	18	18	17	17	17	17	16	16	16	15
51.5:	19	18	18	18	17	17	17	17	16	16
52.0:	19	19	19	18	18	18	18	17	17	17
52.5:	20	20	19	19	19	19	18	18	18	17
53.0:	21	20	20	20	20	19	19	19	18	18
53.5:	21	21	21	20	20	20	20	19	19	19
54.0:	22	22	21	21	21	21	20	20	20	19
54.5:	23	22	22	22	21	21	21	21	20	20
55.0:	23	23	23	22	22	22	22	21	21	21
55.5:	24	24	23	23	23	22	22	22	22	21
56.0:	25	24	24	24	23	23	23	22	22	22
56.5:	25	25	25	24	24	24	23	23	23	23
57.0:	26	25	25	25	25	24	24	24	23	23
57.5:	26	26	26	26	25	25	25	24	24	24
58.0:	27	27	26	26	26	26	25	25	25	24
58.5:	28	27	27	27	26	26	26	26	25	25

* Circumference Value = abdomen + hip - neck circumferences (in inches)

PERCENT FAT ESTIMATION FOR FEMALES

Height (inches)

Circumference Value *	73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5
59.0:	28	28	28	27	27	27	26	26	26	26
59.5:	29	28	28	28	28	27	27	27	26	26
60.0:	29	29	29	28	28	28	28	27	27	27
60.5:	30	30	29	29	29	28	28	28	28	27
61.0:	31	30	30	30	29	29	29	28	28	28
61.5:	31	31	31	30	30	30	29	29	29	28
62.0:	32	31	31	31	30	30	30	30	29	29
62.5:	32	32	32	31	31	31	30	30	30	30
63.0:	33	32	32	32	32	31	31	31	30	30
63.5:	33	33	33	32	32	32	32	31	31	31
64.0:	34	34	33	33	33	32	32	32	32	31
64.5:	34	34	34	34	33	33	33	32	32	32
65.0:	35	35	34	34	34	34	33	33	33	32
65.5:	36	35	35	35	34	34	34	33	33	33
66.0:	36	36	35	35	35	35	34	34	34	33
66.5:	37	36	36	36	35	35	35	35	34	34
67.0:	37	37	37	36	36	36	35	35	35	34
67.5:	38	37	37	37	36	36	36	36	35	35
68.0:	38	38	38	37	37	37	36	36	36	36
68.5:	39	38	38	38	37	37	37	37	36	36
69.0:	39	39	39	38	38	38	37	37	37	37
69.5:	40	39	39	39	38	38	38	38	37	37
70.0:	40	40	40	39	39	39	38	38	38	38
70.5:	41	40	40	40	39	39	39	39	38	38
71.0:	41	41	41	40	40	40	39	39	39	39
71.5:	42	41	41	41	40	40	40	40	39	39
72.0:	42	42	42	41	41	41	40	40	40	40
72.5:	43	42	42	42	41	41	41	41	40	40
73.0:	43	43	43	42	42	42	41	41	41	40
73.5:	44	43	43	43	42	42	42	42	41	41
74.0:	44	44	43	43	43	43	42	42	42	41
74.5:	45	44	44	44	43	43	43	42	42	42
75.0:	-	45	44	44	44	44	43	43	43	42
75.5:	-	-	45	45	44	44	44	43	43	43

* Circumference Value = abdomen I + hip - neck circumferences (in inches)

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(U) In October of 1981, OPNAVINST 6110.1B was promulgated establishing the percentage of body weight contributed by fat mass (%BF) as the basis for weight control decisions. Tables based upon the work of Wright, Dotson, and Davis allowing prediction of %BF from neck, biceps, forearm, abdomen and thigh circumferences were accepted for use on an interim basis. This report covers validation of the equation of Wright and his co-workers, as well as the development and cross-validation of a new equation which offers improved

20. Continued

prediction of %BF for U.S. Navy female personnel.

Anthropometric measures consisting of 8 skinfold thicknesses, 11 body circumferences, height, and body weight were made on 214 female U.S. Navy personnel aged 18-44 years (mean age = 26.5 yrs). In addition, each participant had her body density and %BF determined by underwater weighing.

Validity of the equation of Wright and co-workers was assessed by correlation between predicted and measured %BF. The correlation coefficient = 0.80 (std. err. meas. = 4.19 %BF). Errors in prediction near the Navy minimum standard of 30% BF, dictated development of a new equation.

Factor analysis of the anthropometric variables indicated a suitable equation could be developed using circumferences and height as predictors. An equation was developed using forward, stepwise multiple regression of logarithmic transforms of circumferences and height as predictors of body density determined from underwater weighing. The final equation was: Body Density = -0.350 X log (ABDOMEN I + HIP - NECK) + 0.221 X log(HEIGHT) + 1.296. All measurements are expressed in centimeters. The multiple correlation coefficient for this equation was 0.85 (see = 0.00796 g/cc = 3.72 %BF units).

Cross-validation of this equation using circumference and underwater weighing data collected by another laboratory on a sample of 66 female Canadian Forces personnel, and data collected in our laboratory on a sample of 80 U.S. Navy personnel yielded correlation coefficients of 0.80 (std. error of measurement = 4.36 %BF units) and 0.87 (std. error of measurement = 4.04 %BF units), respectively.

It was recommended that this equation be adopted for the determination of %BF for female Navy personnel.